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Fabrication of Wide-IF 200-300 GHz SIS mixers with suspended metal beam leads formed on SOI

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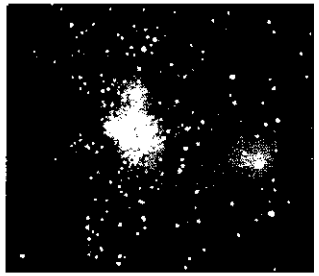
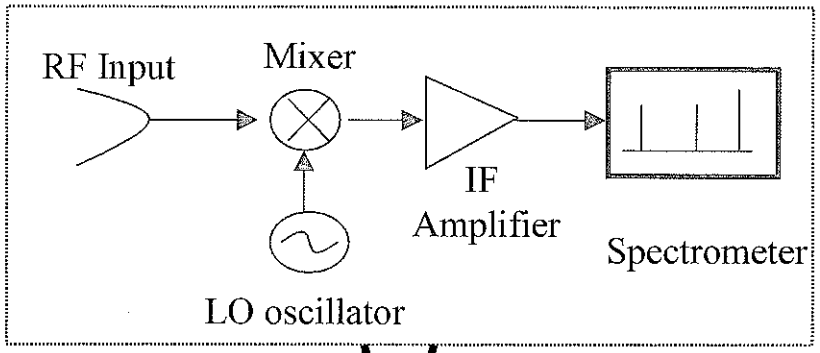
Outline

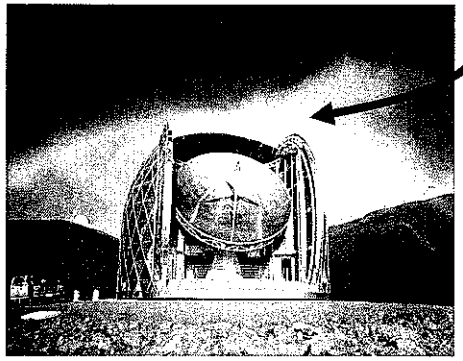
- Heterodyne detection
- Design considerations
- Prior work
- Process development of SIS mixers on SOI
- Device measurements
- Summary

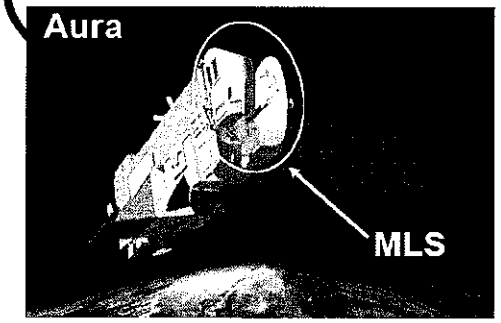
Heterodyne Detection



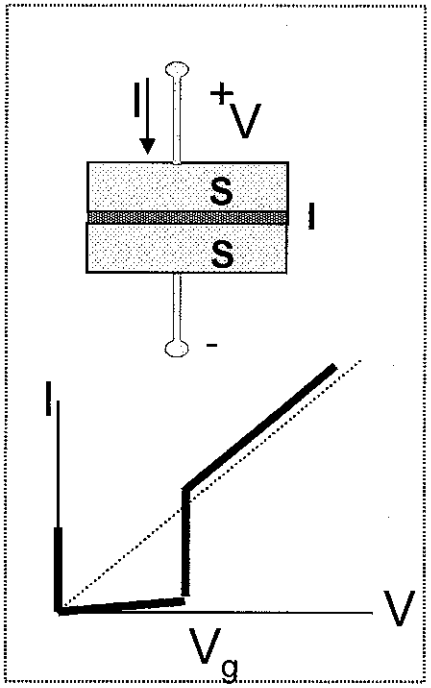
molecular vibrations: distant galaxies, earth's atmosphere







SIS Mixer



- SIS offers increased sensitivity, spectral resolution, bandwidth typically 1-3 GHz
- Describe process by which SIS mixers are fabricated on ultra-thin membranes of Si, with suspended metal beam leads in order to improve bandwidth

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Heterodyne Mixers in Atmospheric Chemistry

Schottky Mixers

1st Generation (UARS MLS)

Radiometers at 63 GHz, 183 GHz, 205 GHz

- Understanding ozone depletion in earth's upper atmosphere, global effects of pollution

2nd Generation (EOS MLS) launched on Aura satellite (7/04)

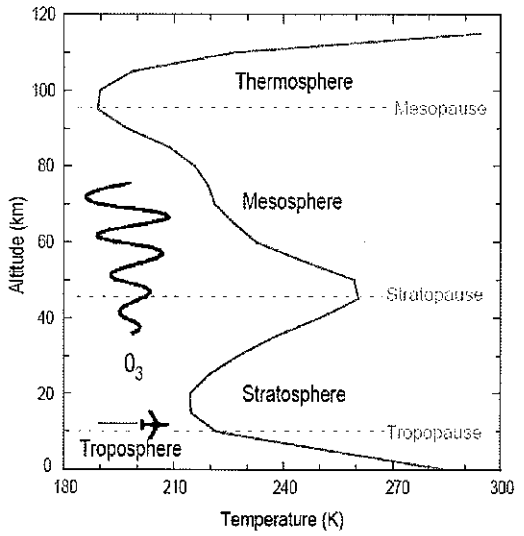
Improves spectral coverage between 100 GHz – 2.5 THz

SIS Mixers

Proposed 3rd Generation mission (SMLS)

Extend from stratosphere into troposphere

- SIS mixers will have improved sensitivity, required due to presence of ice clouds, dense volcanic aerosol, smoke
- Improved bandwidth will reduce scan times and help in observation of weak, pressure broadened lines



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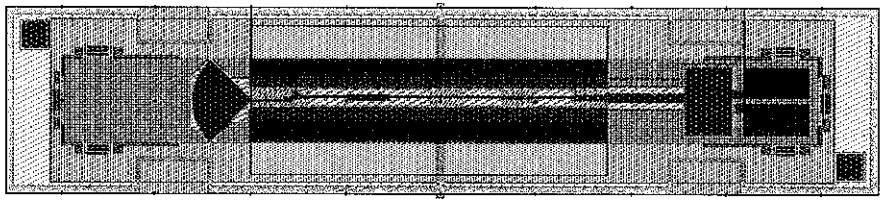
Wide-IF bandwidth of SIS Mixer

Wide-IF bandwidth enabled by RF design

1. **Type of Substrate**: High ε_r to keep impedance nearly real in 200-300 GHz band. Choose Si ε_r (Si) = 11.6 compared to ε_r (quartz) = 3.8
2. **Dimension of substrate**: Thinner substrate → $\omega_c \pi \frac{1}{\sqrt{\varepsilon_r}} \left[\frac{1}{a^2} + \frac{1}{b^2} \right]^{-\frac{1}{2}}$
3. **Good RF ground** → suspended metal beam leads

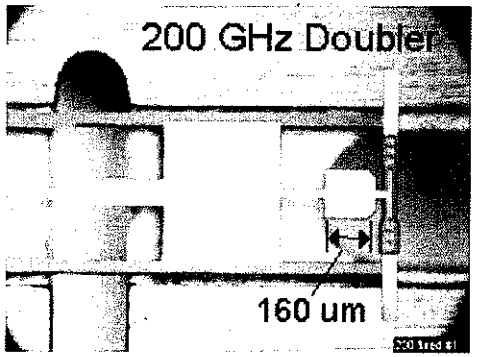


Fabrication/Material considerations

- SOI substrates: Si of desired thickness, uniformity obtained easily, scalable with frequency
- Si thermal and mechanical properties more advantageous compared to quartz
  - Thermal conductivity: ~150 W/mK (Si); 2 W/mK (quartz)
  - Rupture modulus ~ 135 MPa (Si); 50 MPa (quartz)
- Use micromachining techniques to form mixer devices with suspended metal beam leads

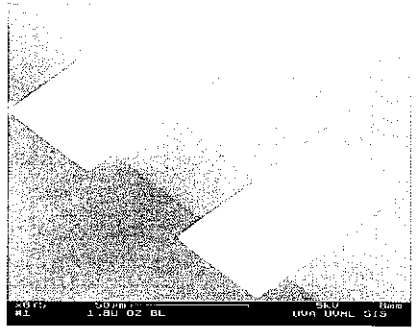
Beam Leads: Prior Work

- SWAT Group, JPL
  - GaAs schottky mixers with beam leads
  - GaAs substrate wax-mounted and thinned using lapping



Source: Imran Mehdi, SWAT team

- University of Virginia Group
  - Beam leads on quartz
  - Use a front-side process, without SIS mixer devices



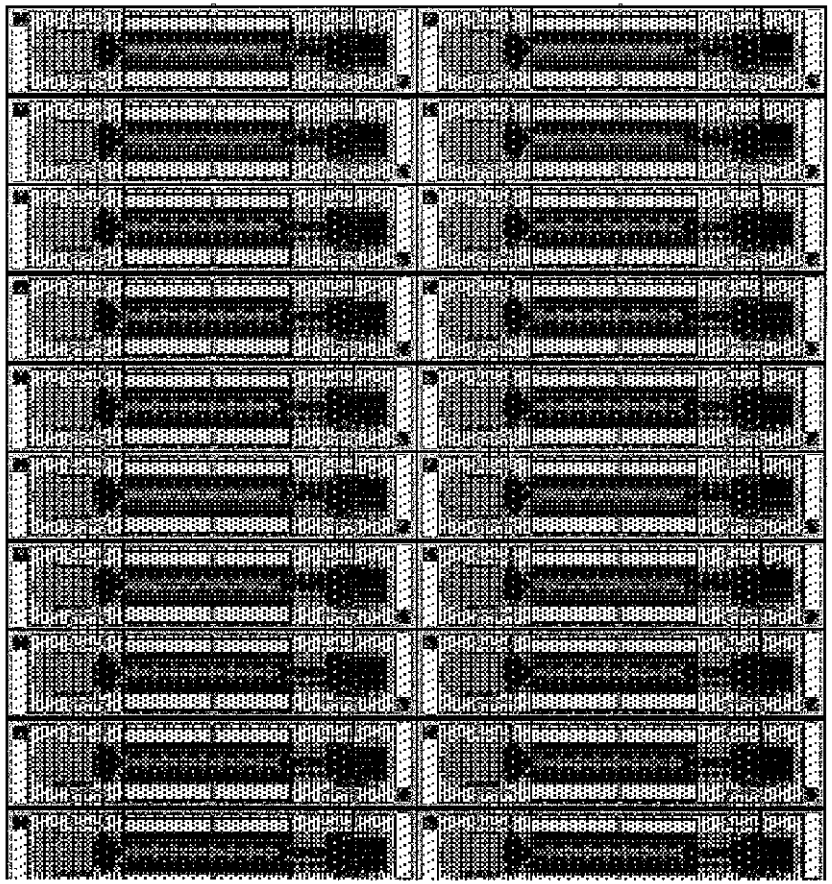
Source: A. Lichtenberger, UVA

- SIS Group, JPL
  - SIS mixers fabricated on thin SiNx membranes
  - SiNx grown using CVD

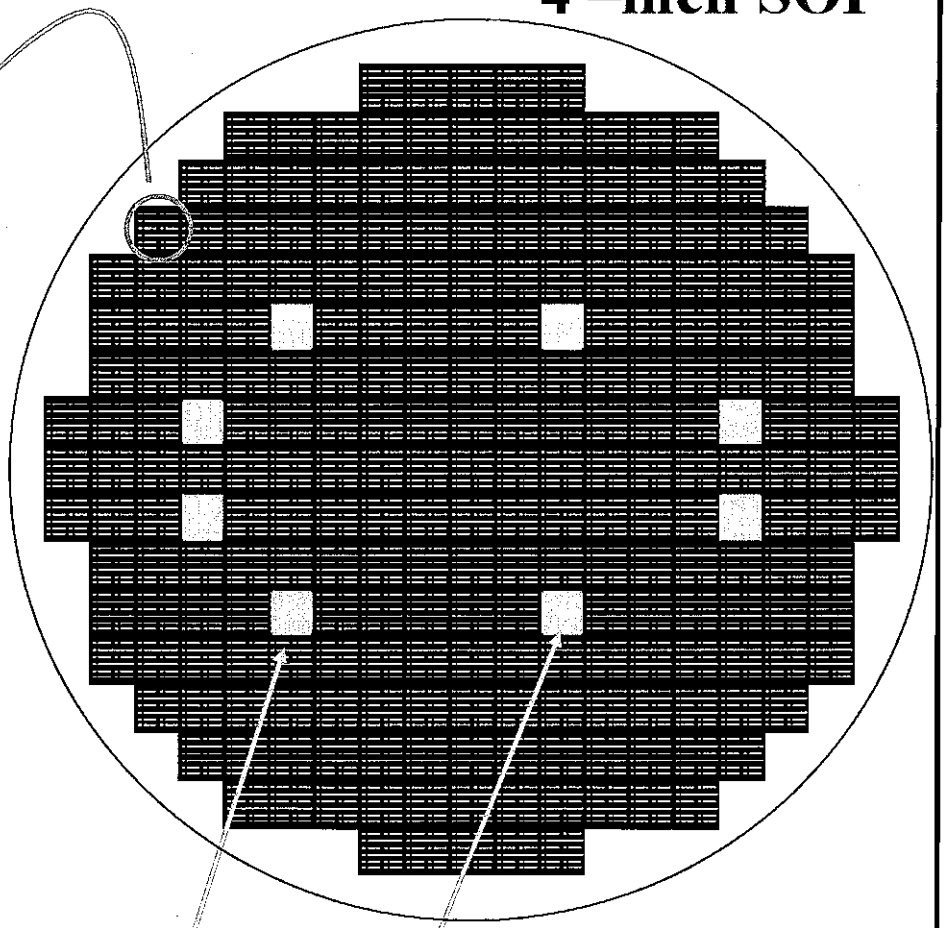
- **This Work**
  - Use thin Si from SOI substrates
  - SIS mixer devices with beam leads
  - Lithographic dicing

Layout

Single die containing mixer devices



4 –inch SOI



Diagnostic die

Process Development

I. Front-side

- SIS mixer fabrication
- Growth of beam leads

II. Mounting

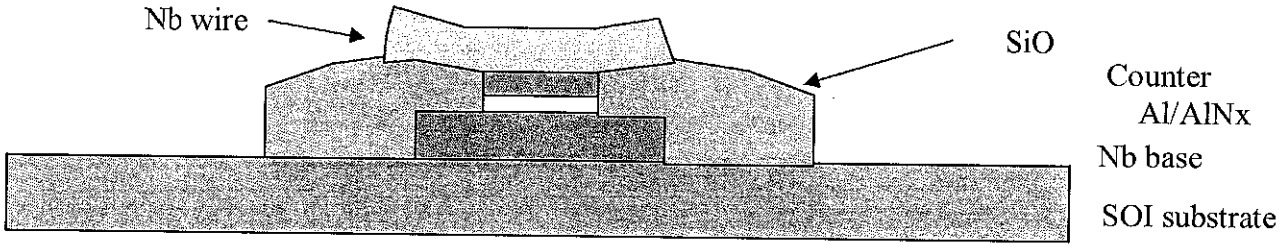
- Wax mount

III. Back-side

- Handle removal
- Device partitioning lithography
- Anisotropic Si etch

IV. Device Release

I. Front-side process: SIS device fabrication

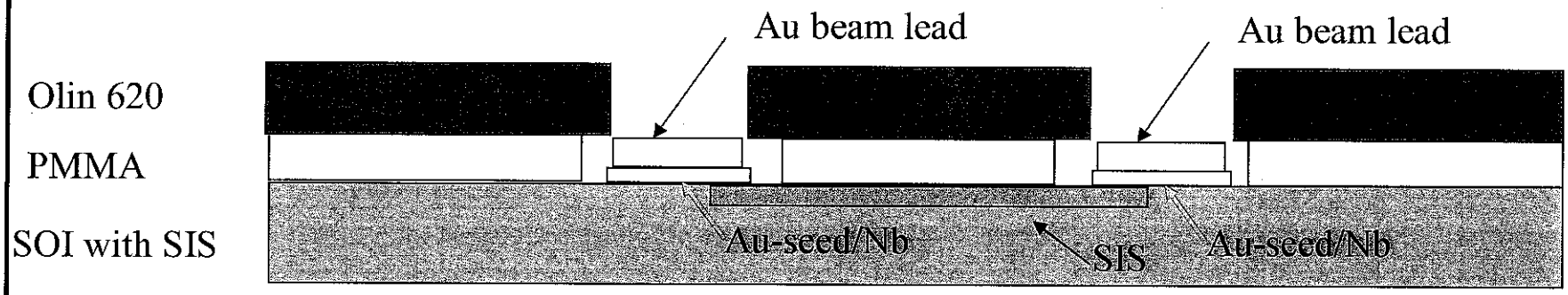


Layer	Deposition method	Thickness (A)
Nb base/Al	DC magnetron sputtering	~2000/90
AlNx	RF nitridation	-
Nb counter	DC magnetron sputtering	~ 700
SiO	Thermal evaporation	~ 3000
Wire	DC magnetron sputtering	~ 4000

Mask layer	Lithography	Etch Chemistry
Ground plane	Shipley 660, AZ 300 MIF	BCl_3/Cl_2
Junction	Shipley 660, AZ 300 MIF	$CF_4/CCl_2F_2/O_2$
Wire	Olin 620, AZ 300 MIF	$CF_4/ CCl_2F_2/O_2$
Beam leads	950 k 5% PMMA/Olin 620, chlorobenzene	Lift-off
Device partitioning	AZ 4330, 300 MIF	DRIE, SF_6/C_4F_8

I. Front-side process: Beam-lead Growth

- Bi-layer lift-off technique, (PMMA/resist), easier lift-off of metal films



- Nb/Au seed layer
- E-beam evaporation for Au deposition
  - low deposition rate to enhance quality @ low base pressure; t ~ 1 μm
  - Low impurity incorporation during growth
  - Lift-off of PMMA/resist (acetone, 80 C)
- Plating is alternative technique for thicker films, higher growth rate
- After beam leads grown on SIS devices, front-side process complete

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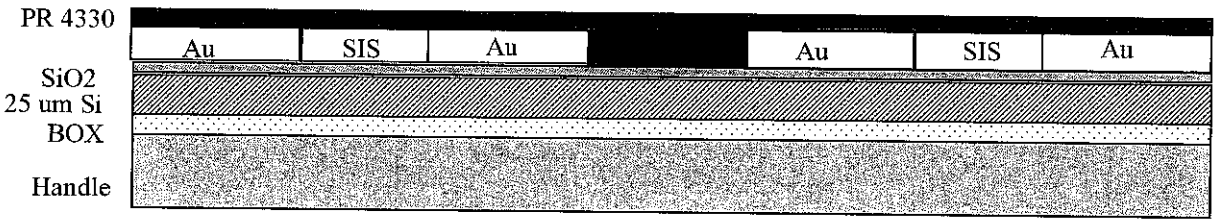
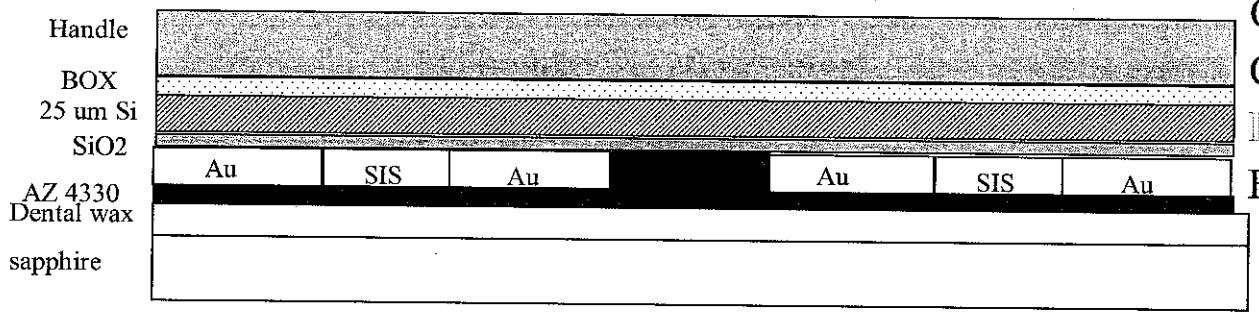
II. Mounting

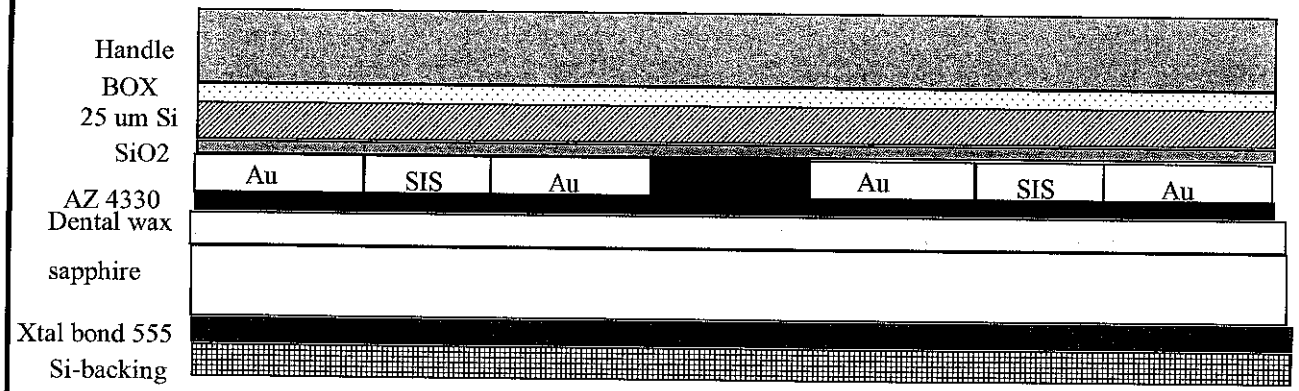


UV tape



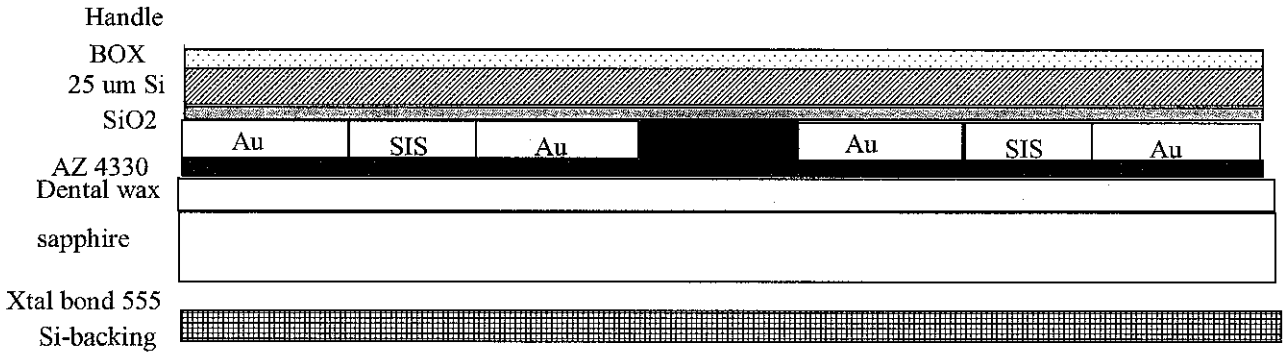
OCON 195 (60 C/acetone)
C.bond 555 (70 C/water)
Dental wax (90 C/toluene)
Blanchard (130 C/acetone)

115 C



55 C

III. Back-side process: Handle layer removal

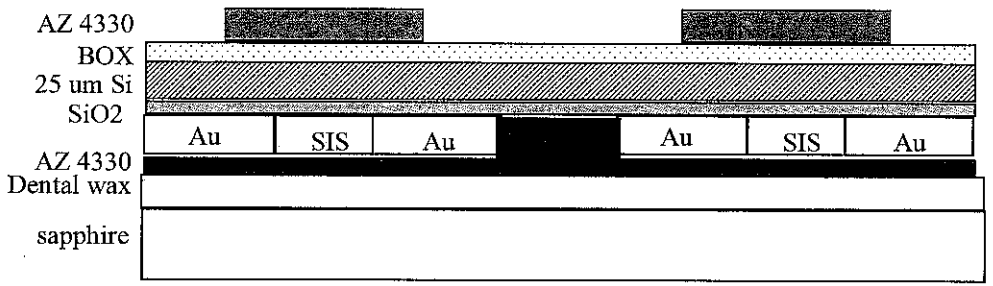


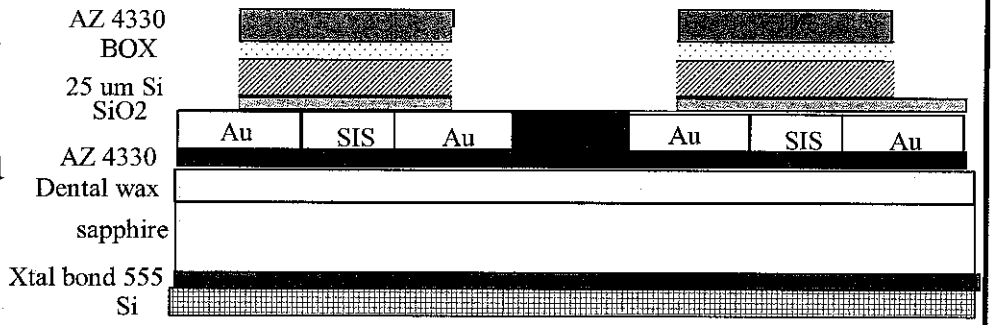
DRIE of SOI handle layer in STS

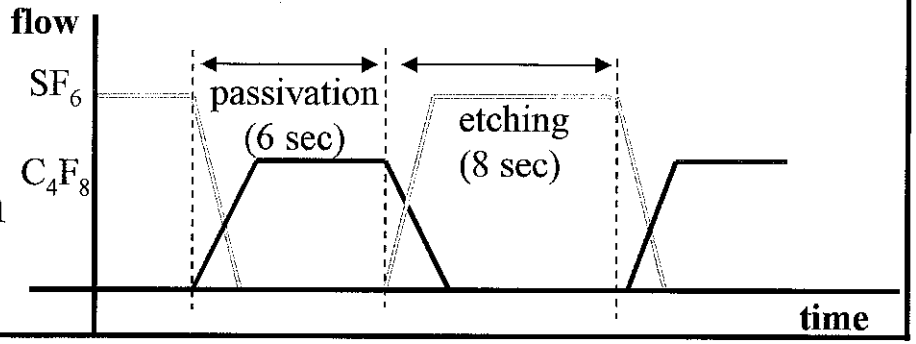
- SF_6 flowed constantly, continuous mode, isotropic etch
- Etch rate ~ 2.33 μm/min to etch 350 μm of Si
- Back of substrate cooled with LiHe

III. Back-side Process: Device Partitioning

- Spin 4330 resist
  - Lower temperature, longer bake (50 C, 1 hr)
- Expose in 1:1 Karl Suss
  - Relieves focus tolerance requirement
  - Front-side marks viewed thru optically clear wafer/wax
- Develop in AZ 300 MIF
- Anisotropic Si-etch
  - Etch 25 μm Si, pulsed mode, SF_6/C_4F_8; etch rate ~ 1.1 μm/min

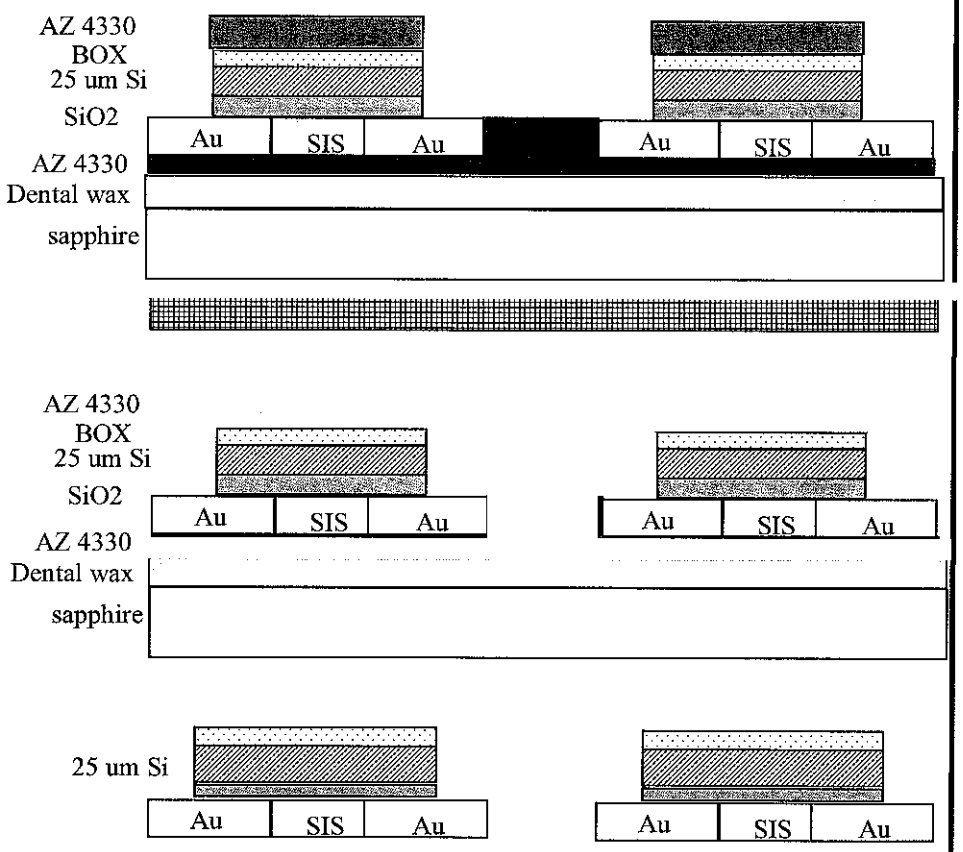




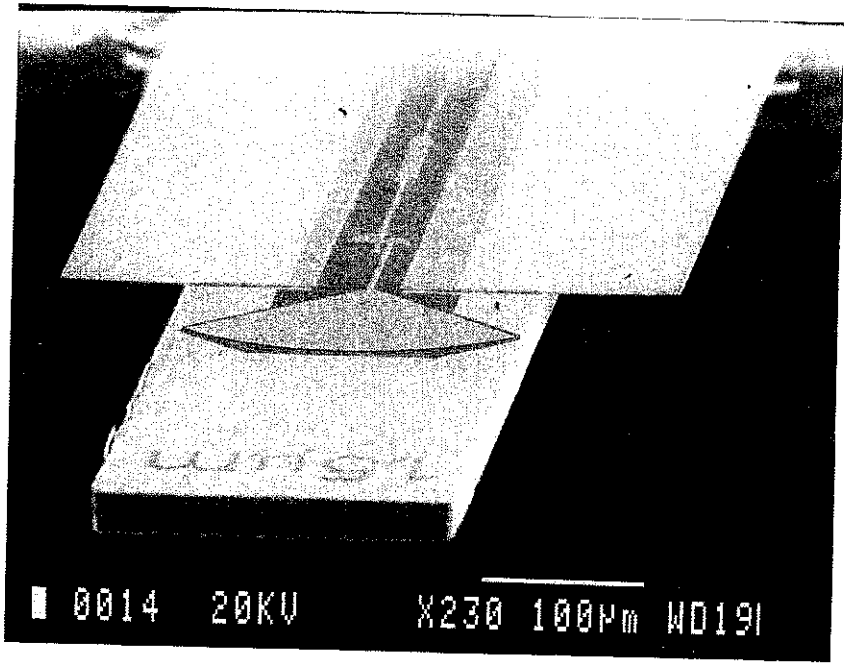


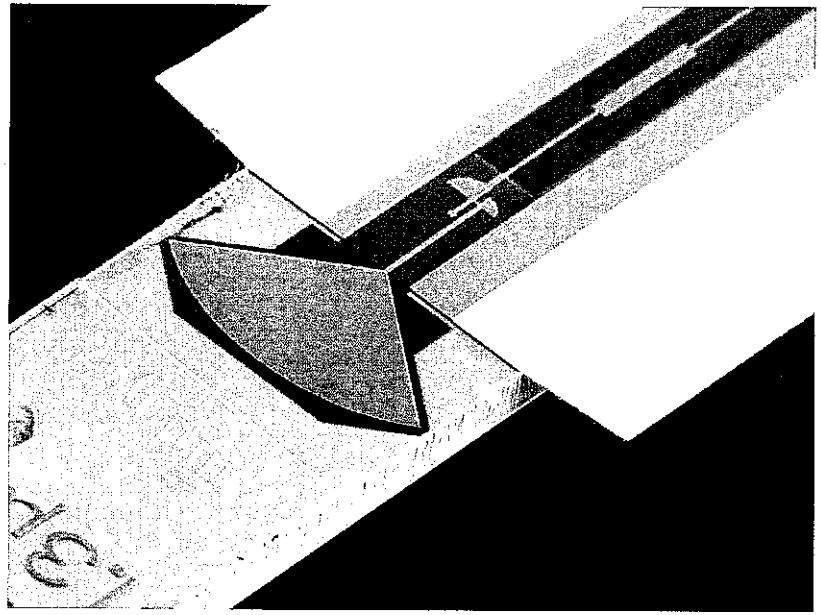
IV. Device Release

- Prior release clean
  - Light O_2 clean
  - Remove Si-backing wafer by dissolving xtal bond in water
- Final release
  - Release by dissolving resist in acetone at 50 C, ~ 1 hr-2 hrs
  - Devices collected on filter paper
  - Additional cleaning done in PRS stripper at 80 C
  - Acetone, IPA soak

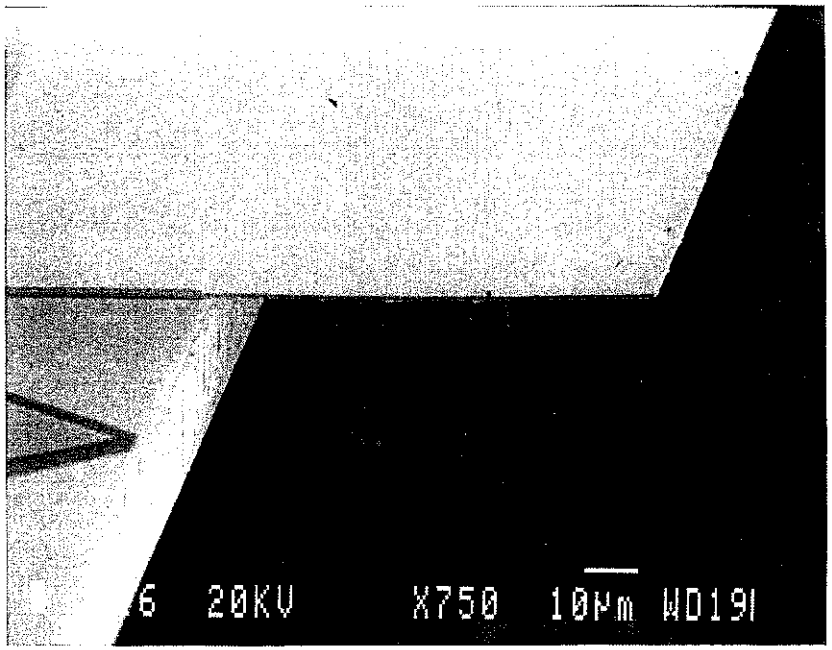


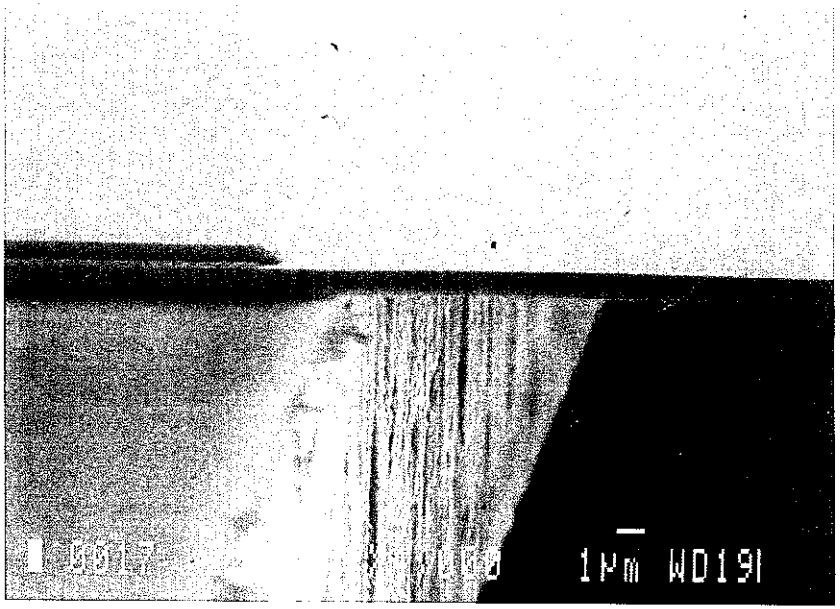
SEM of Beam-lead Mixer Devices





Close-up of Beam-lead Area

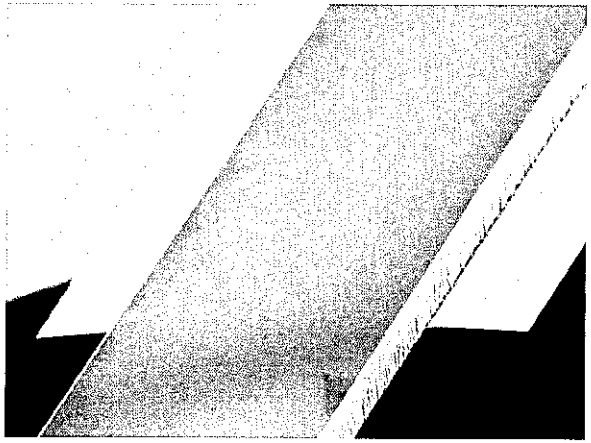




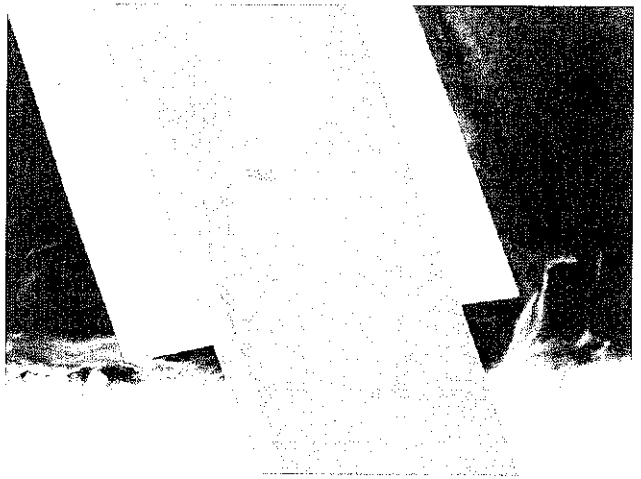
Beam leads can withstand a torque of 48 inch-ounce when placed in mixer block.

Backside of Beam-leads

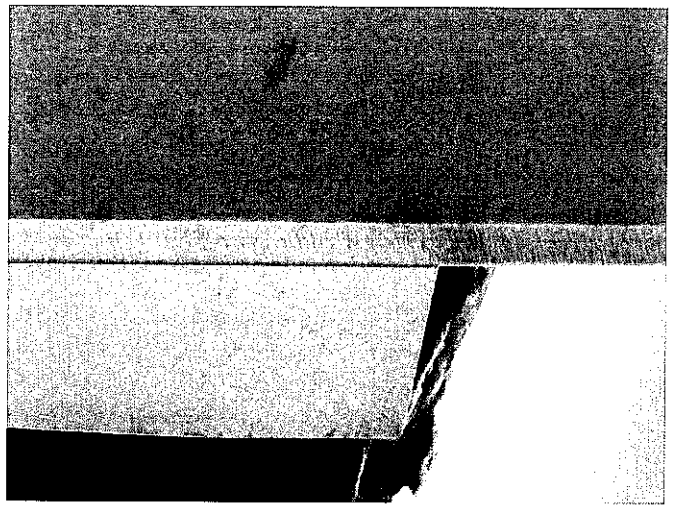
SiO_2 buffered SOI



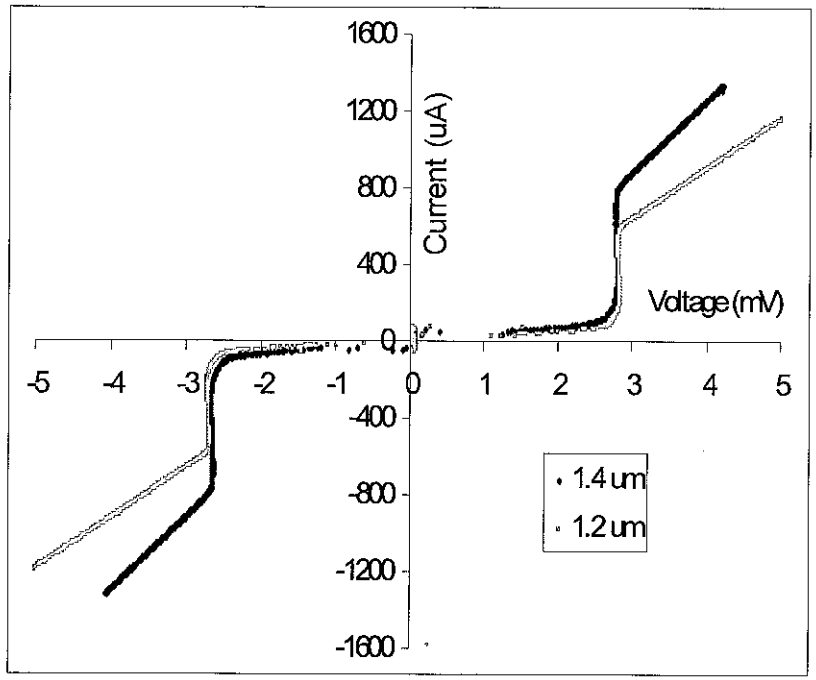
AlN_x buffered SOI

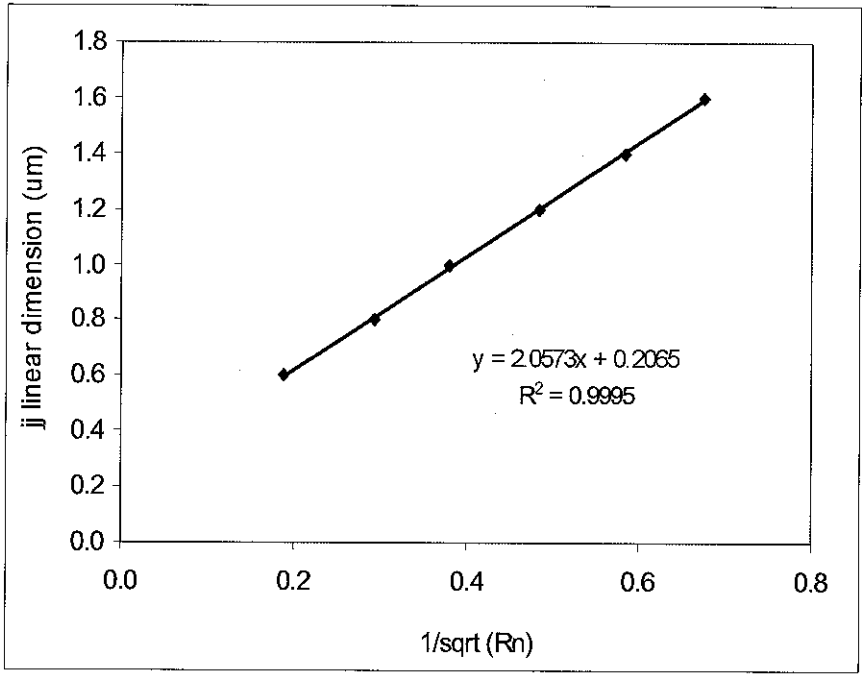


- Nano-pillars observed on back of beams grown on SiO_2 buffered SOI
  - Possibly arising from CF_4/O_2 etch of oxide
- Leads on AlNx buffered SOI look smooth, electrical performance should be OK



Electrical Measurements

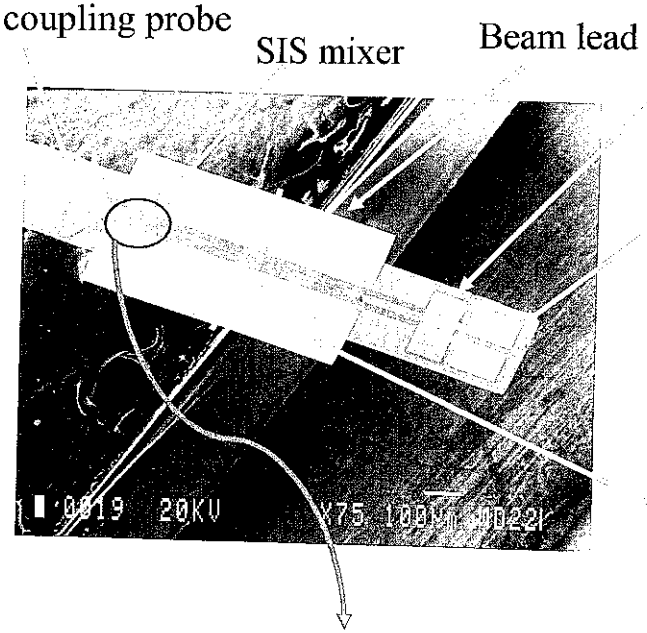


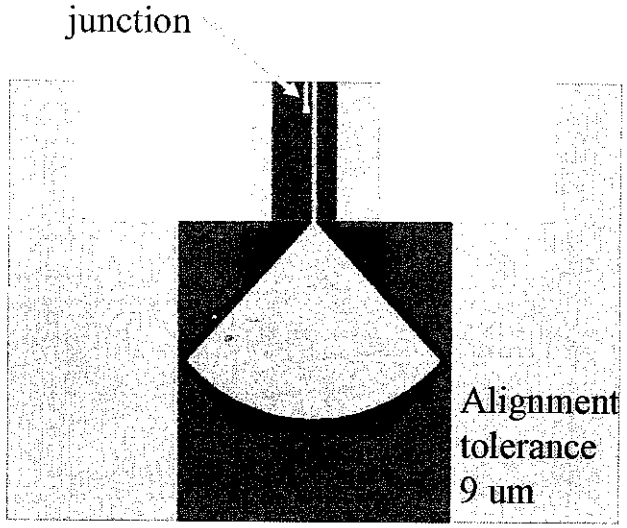


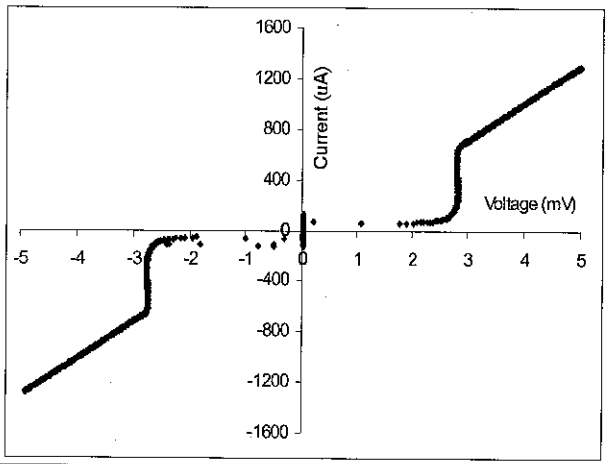
$J_c \sim 44$ kA/cm^2, $V_g \sim 2.75$ mV
max. $R_{sg}/R_n \sim 10$

Fit to Ambegaokar-Baratoff expression
($I_cR_n \sim (\pi/4)\ V_g$, empirically → 190 mV)
Extract J_c → includes statistical variation from junction-to-junction

Mixer Devices







Preliminary noise temperatures measured to be ~ 70 K.

Summary

- Developed fabrication process that utilizes micromachining techniques to form SIS mixers on SOI substrates with suspended metal beam leads
  - Wax-mounted, back-side process
  - Incorporates lithographic dicing compared to manual dicing as with quartz
- Beam-leads appear flat at 1 μm thickness
  - Mechanical tests show beam leads survive a torque of 48 inch-ounce when placed in mixer block
  - Thicker beams can be electro-plated
- Junctions on diagnostic chip and mixers are electrically functional
  - SIS devices temperature sensitive, quality degrades due to diffusion at Nb/Al interface
  - SOI process appears compatible with conventional SIS device fabrication
- Beam lead process should be scalable to higher frequencies
  - Future missions may require higher frequency channels, $f_{3dB} \sim 1/t$, SOI with t down to 1 μm available
- Future designs could incorporate beam leads on bias pad, reducing parasitics